APPLICATION

FOR

UNITED STATES LETTERS PATENT

TITLE: DETECTING CONTRABAND BY EMPLOYING INTERACTIVE MULTIPROBE TOMOGRAPHY

APPLICANT: KRISTOPH D. KRUG, MICHAEL ELLENBOGEN, PAUL J. HURD, JOHN O. TORTORA

DETECTING CONTRABAND BY EMPLOYING
INTERACTIVE MULTIPROBE TOMOGRAPHY

5   The present invention relates to interactive, flexible geometry, multiprobe inspection systems for examination of packages or baggage.

Background of the Invention

      Over the past several years, X-ray baggage

10 inspection systems have evolved from simple x-ray imaging systems that were completely dependent on interpretation by an operator to more sophisticated automatic systems that can automatically recognize certain types of contraband. The more sophisticated inspection systems have employed single

15 energy or dual energy X-ray radiation transmitted through or scattered from the examined baggage. Some systems have used a single view source detector arrangement, others have utilized a dual view or multi-view arrangements. The single or dual view systems usually scan baggage, as it moves on a

20 conveyor, using a fan beam or a scanning pencil beam of X-rays in a fixed geometry. The multiview, Computed Tomography (CT) type systems usually scan stationary baggage in a fixed geometry of scan angles and process data corresponding to absorption of X-rays to reconstruct

25 selected slices of the baggage.

      At airports, the baggage inspection procedure is divided into at least three levels of inspection. A 'level 1' system processes baggage rapidly, ideally at a rate of up to 1500 bags per hour. This system is located at a first

30 inspection station and inspects all baggage; as such, it represents the first line of defense. The system rapidly scans baggage and automatically makes a decision based on its particular modes of detection and methodology. This methodology may be object based, e.g., mass density,

effective atomic number (Z_{eff}), or Compton X-ray scatter, or it may be bag-based, such as Nuclear Quadrupole Resonance (NQR), ion mass spectroscopy, vapor chemi-luminescence, or other techniques. Such systems are able, to some degree, to
5 rapidly eliminate "clean" and non-suspicious baggage from the stream of passenger baggage and have been proven effective in detecting real threats. The number of bags that cannot be cleared at level 1 can range from 10% to 50% of the total number of bags. The clearing efficiency
10 depends on the particular detection methodology and threat thresholds used in the system.

The rejected (i.e., non-cleared) bags are automatically sent to a 'level 2' area. In the 'level 2' area, an operator usually visually inspects an x-ray image
15 of the rejected bag and attempts to determine whether a suspicious object inside the bag can be cleared based on its obvious shape. The operator searches the image for characteristic objects such as weapons, timing and detonation devices, wires, or other characteristics
20 associated with contraband. The operator at this station can clear most, but not all of the rejected bags. The remaining baggage, which is usually 0.1% to 0.5% of the initial stream, is then sent on to a 'level 3' inspection station which is usually a slower inspection device that
25 uses a different technology.

Vapor or trace detectors (also called 'sniffers') and CT scanners have been used as 'level 3' devices. A vapor or trace detector does not employ a penetrating type of radiation, but looks for traces of characteristic
30 materials. It was suggested that, by careful placement inside a bag, a relatively large amount of explosives can pass undetected by the trace device. On the other hand, a

CT scanner, which of course employs penetrating X-ray radiation, is usually successful in identifying explosives inside a bag especially when present in a large amount. The CT scanner basically measures a single parameter, that is,

5　the mass density of the examined object. The CT scanner can be set up to communicate with the 'level 1' device in order to interrogate a specific object identified within the baggage by that device. If a 'level 1' X-ray scanner identifies threats on the basis of effective atomic number

10　(Z_{eff}) the additional density information from the CT scanner can significantly reduce the false alarm rate, but may not be able to eliminate it completely. However, CT scanners can be very expensive considering the low utilization at a 'level 3' station.

15　On average, 'level 3' devices clear less than half of the inspected objects, yielding 0.05% to 0.25% of the baggage to be sent to 'level 4'. 'Level 4' is defined as reconciliation with the owner. The reconciliation is often difficult, if not impossible. When the reconciliation is

20　not possible the bag is confiscated, which causes a complaint from an unhappy passenger.

While the above system can perform successfully, there is still a need for a relatively low cost X-ray inspection device that can reliably detect various

25　explosives (or other contraband) having different shapes and being located anywhere in the examined baggage. Such a device should have a high confidence and a low false alarm rate.

Summary of the Invention

30　In general, the inspection system detects different types of contraband (e.g., explosives, drugs, money) in

items of baggage or packages by one or more material
sensitive probes deployed on an arm or scanner that is
positioned mechanically to examine the item of luggage with
many different and programmable views including radial and

5   axial views. The inspection system includes an X-ray probe
that has an x-ray source and a detection system with one or
more detector arrays. The x-ray source and the detector
arrays are constructed to move together in a coordinated
fashion. Thus the X-ray probe can take CT type data and can

10 also reconstruct cross-sectional and mass density
information. The X-ray probe also includes programmable
collimation and filtering to generate filtered pencil beams
for Rayleigh and Compton scattering measurements. Dual
energy x-ray projection data can be taken by setting one of

15 several fan beam collimators and scanning along a linear
axis. The detection system includes an array of dual energy
transmission detectors and Rayleigh scattering detectors
with programmable collimation. The detection system may
also include arrays of Compton scatter detectors mounted on

20 the scanning head and under the table holding the inspected
item.

        The inspection system includes several different
modes of detection operating in conjunction with an expert
system of computer software and detection algorithms to

25 effect a very high confidence x-ray scanner for explosives
detection in luggage. The inspection system may also
include a graphical interface and an operator interface that
enable interactive communication with the detection
algorithm.

30   In general, an X-ray inspection method of detecting
a specific material of interest in items of baggage or
packages includes employing X-ray radiation transmitted

through or scattered from a examined item to obtain multi-view spatial information about the examined item, identifying from the spatial information a suspicious region inside the item, employing a material sensitive probe to

5   acquire material specific information about the suspicious region, and identifying, based on computer-processing, presence of the specific material in the suspicious region.

The material sensitive probe may utilize a Compton scattered X-ray radiation, a Raman spectrum, an infrared

10   spectrum, *The* nuclear quadrupole resonance effect, *a wave of microwave energy modified by* dielectric material property, or reflected millimeter wave (microwave) field. The material sensitive probe may have directional properties such as a coherent scatter probe.

15   X-ray radiation is employed by exposing the examined item at multiple locations to a fan beam of X-rays, detecting X-ray radiation transmitted through or scattered from the examined item, and processing the detected X-ray data to identify the suspicious region. The detection is

20   performed by detecting X-ray radiation transmitted through, back-scattered or forward-scattered from the examined item.

The introduced X-ray radiation may be a fan beam or a pencil beam generated at at least one energy.

The detection of coherently scattered X-rays may be

25   performed by employing a position sensitive or an energy sensitive X-ray detector.

Brief Description of the Drawings

Fig. 1 is a schematic top view of a baggage inspection system employing two x-ray inspection devices.

30   Figs. 2 shows a schematic side view of an x-ray inspection device employed in the system of Fig. 1.

Fig. 3 shows a cross-sectional view of the inspection device of Fig. 2.

Figs. 3A, 3B, and 3C are cross-sectional views of the inspection device of Fig. 2 at different angles of

5   operation.

Figs. 4, 4A, 4B and 4C are block diagrams of the device of Fig. 2.

Fig. 5 shows diagrammatically an coherent scatter X-ray probe employed in the device of Fig. 2.

10   Fig. 6 is a flow diagram of operation of the device of Fig. 2.

Description of the Preferred Embodiments

Referring to Fig. 1, an X-ray inspection system 10 includes a level one x-ray inspection device 12, such as

15   VIVID Rapid Detection System (available from Vivid Technologies, Inc., Waltham, MA), which examines items of baggage being transported on a conveyor 16. When device 12 examines an item of baggage 14A and evaluates the item as free of regions that could contain contraband, the item is

20   automatically directed by a baggage pusher 18 to proceed further on conveyor 20. If device 12 detects possible presence of contraband, pusher 18 directs baggage 14B to conveyor 22 that transports the baggage to an X-ray inspection device 30, such as a modified version of a QDR

25   4500 scanner (available from Hologic, Inc., Waltham, MA). An operator located at a remote location 32 can oversee the entire inspection process, evaluate data detected and processed by inspection device 12 and direct operation of inspection device 30.

30   Referring to Figs. 2 and 3, X-ray inspection device 30, enclosed in shielding 28 (Fig. 1), includes several

material sensitive probes.   These probes are located on a C-arm 40, which utilizes displacement subsystems 42 and 44 to move linearly along or to rotate relative to a moving platform 34 and a frame 35.   A first probe utilizes

5   polychromatic X-ray radiation to scan baggage 14B at several angles to locate suspicious objects or regions.   Based on multi-view X-ray transmission data, the first probe creates images of article surrounding the suspicious objects or regions and also identifies the best examination geometry

10   for a second stage probe.

         The system uses several different probes with directional or non-directional properties in the second stage of examination.   A preferred directional probe employs the X-ray diffraction technique using the geometry provided

15   by the first probe.   Other second stage probes utilize Raman spectroscopy, infrared spectroscopy, NQR, or microwave imaging as will be described below.

         The first, multiview, polychromatic X-ray probe includes an x-ray source subsystem 46, an X-ray detector

20   subsystem 50 and the corresponding electronics shown diagrammatically Fig. 4A.   X-ray source subsystem 46 has an X-Ray tube, a collimator and an X-ray controller 48 that includes an X-Ray tube filament transformer, a high voltage rectifier circuit, and sensing circuits that monitor the

25   high voltage applied to the x-ray tube and the beam current. The X-ray controller, which can operate both in pulsed mode or in a continuous mode, triggers the X-ray source (e.g., a tungsten X-ray tube) that can produce a beam of X-rays at high and low energy bands.   (A suitable X-ray controller is

30   disclosed in U.S. Pat. 5,319,547, which is incorporated by reference.)   The emitted X-ray radiation is collimated by the collimator to create a fan beam of X-ray radiation 47.

X-ray detector subsystem 50 includes 72 scintillating $CdWO_4$ crystals, each optically coupled to one photodiode. Each photodiode detects light emitted the corresponding crystal and converts the light into current,

5   which is amplified in a current-to-voltage converter. Output from the amplifier is applied to an integrator through analog switches. The analog switches, which operate in parallel, are turned on during the X-ray pulse and turned off during the integrator hold time to prevent integrating

10   noise into the data. The control signal that turns these switches on and off is supplied from an integrator/multiplexor board 114.

Integrator/multiplexor board 114 sends the analog signals to an analog-to-digital (ADC) board 112 for

15   conversion to a digital format. The analog signals from integrator/multiplexor board 114 are applied to differential amplifiers on ADC board 112 in four groups of up to 64 channels. Outputs from the differential amplifiers are combined in a final multiplexor consisting of four analog

20   switches. The multiplexed signals pass through a programmable gain amplifier and summing amplifier before being applied to the A/D converter. The A/D converter converts the analog signal into 16 bit parallel data for processing by a digital signal processor, e.g., Motorola

25   56000. The digital signal processor generates all the control signals necessary for the detector array assembly. This processor also provides a high speed serial data link to computer 70.

Also referring to Fig. 4, inspection device 30 also

30   includes a computer 70, which controls and commands the hardware. Computer 70 is connected to a distribution board 80, which provides interconnections between an operator's

console 33, C-arm interface 110 (Figs. 4A, 4B or 4C), control panel controller 84 and displacement subsystem 42 and 44. Control panel controller 84 interfaces a control panel 86 to operator's console 33. Control panel 86

5   provides switches including visual indicators for moving C-arm 40 and platform 34. Linear displacement subsystem 42 includes TX and TY stepper motors and a rotational subsystem 44 includes C-arm rotation motor 98 and a C-arm carriage motor 102. TX stepper motor driver 88 controls the motion

10   of platform 34 using a driver motor 90 based on commands from computer 70. A position encoder associated with motor 90 provides position monitoring. TY stepper motor 94 and associated driver 92 provides the motion of platform 34 in the direction of baggage movement and its position is

15   tracked by an associated position encoder. An AR stepper motor driver 96 controls the rotation of C-arm 40, which is moved by a C-arm rotation motor 98 and its position controlled with an associated position and coder. A C-arm 40 carriage motor 102 moves C-arm 40 linearly and an

20   associated position encoder provides position monitoring. The left or right movement of C-arm 40 is controlled by an AY stepper motor driver 100. A platform motor raises or lowers platform 34 and the corresponding position encoder provides position monitoring. The motion of motor 106 is

25   controlled by a DZ drive motor controller 104.

         Device 30 is interfaced to a ISA Bus computer to control table and C-arm movement and X-ray generation, perform all necessary calculations, and manage baggage and database information. The system uses a computer with a

30   pentium processor, a 16 Mb of memory and a super VGA video card.

Referring to Fig. 5, the second probe, which is a coherent (Rayleigh) x-ray scatter probe 140 is also located on C-arm 40. Coherent x-ray scatter probe 140 includes a polychromatic X-ray source 142 emitting X-ray radiation

5 collimated by a pencil beam collimator 144. X-ray source 142 shares the tungsten X-ray tube with X-ray source 142 of the first probe. (Alternatively, X-ray source 142 uses a separate X-ray tube.) Collimator 144 is located on and controlled by aperture motor and sensor 118 (Fig. 4A).

10 Pencil beam 146 is filtered by an erbium filter 148 or a thulium Ross filter 150 before it irradiates the examined object (155). Filtered X-ray beam 152 is scattered by the examined object and the characteristic radiation (158) is detected by a coherent scatter X-ray detection subsystem

15 160. Detection subsystem 160 includes a collimator 162 limiting the view angle of the X-ray detector. The X-ray detector includes a position sensitive PMT 166, which detects spatial location of optical radiation emitted from a NaI scintillating crystal 164. The detection geometry was

20 selected to substantially avoid interaction of other obscuring, objects (154a, 154b) with the probe beam.

This probe uses a technique utilizing as a Ross filter, also called a balanced filter, and was described by B.D. Cullity in "Elements of X-Ray Diffraction"

25 Addison-Wesley Publishing Company, Inc., 1978. Since the filters (148 and 150) are made of two different substances differing in atomic number by one, then they have the same relative attenuation at every wavelength except for the narrow band of wavelengths between the K edges of the two

30 substances. When the diffraction pattern from a substance is measured first with one filter and then with the other filter, the difference between the two measured diffraction

patterns yields the diffraction pattern corresponding to a
nearly monochromatic beam with an energy at the K edge.
Advantageously, this measurement does not require
determination of the photon energy of the coherently

5   scattered X-rays. The employed filters have K edges
respectively just below (57.43 Kev) and just above (59.32
Kev) the characteristic K_α of tungsten (58.87 Kev). Thus,
their band pass region coincides precisely with the
strongest emission band of tungsten. The detailed balancing

10   of attenuation between the two filters is accomplished by a
physical balancing of the relative thickness of the two
filters or by the detection software.

         In another embodiment, the coherent x-ray scatter
probe 140 measures accurately the energy spectrum of the

15   scattered photons at several different locations. The probe
measures the entire energy spectrum or only selected
energies corresponding to selected materials. It utilizes
different types of coherent x-ray scatter measurements
described in the prior art (see (1) Strecker, H., Harding,

20   G., Bomsdorf, H., Kanzenbach, J., Linde, R., Martens, G.
"Detection of explosives in airport baggage using coherent
X-ray scatter." SPIE vol.2092 Substance Detection Systems
399-410 1993; (2) Luggar, R.D., Gilboy, W.B., MacCuaig, N.,
"Industrial potential of Rayleigh scattered X-rays for

25   identification of low-Z materials", SPIE Vol. 2092 Substance
Detection Systems, pp. 378-386, 1993; (3) Speller, R.D.,
Horrock, J.A., Lacey, R., "X-Ray scattering signatures for
material identification" SPIE vol. 2092 Substance Detection
Systems, pp. 366-377, 1993; and (4) Luggar, R.D., Horrocks,

30   J.A., Speller, R.D., Royle, G.J., Lacey, R. "Optimization of
a low angle x-ray scatter system for explosive detection"
all of which are incorporated by reference).

Fig. 4B shows diagrammatically an interface for both coherent (Rayleigh) scatter probe 140 and a Compton scatter probe 275. A switchable filter/collimator subsystem includes a filter/collimator motor and sensor 262 controlled
5 by a filter/collimator driver 260. The filter/collimator subsystem selectively position K-edge filtration and a foil collimation system into X-ray beam 146 to enable optimum detection of a selected material. The scattered radiation is detected by detection subsystem 160 that includes
10 position sensitive detector (i.e., scintillating crystal 164 and PMT 166 of Fig. 5) with the corresponding electronics 270 and a position/height discriminator 264. Rayleigh detection subsystem 160 is capable of discriminating the position (268) and energy (266) of each interacting event.
15 The position and energy data are sent to a computer via C-aram interface 110.

Compton scatter probe 275 includes a array of PMT detectors and the corresponding electronics (272) mounted underneath table 34. The scatter array, constructed as
20 described in the above-referenced patent application, is moved to a desired position by motor 280 controlled by driver 282. The scatter array programmably scans along the axial axis of the examined item to reconstruct a 2-dimensional map of back-scattered X-ray radiation. Forward-
25 scattered X-ray radiation is detected by an additional forward-scatter array, or the Rayleigh detection subsystem is set to detect Compton scatter.

Fig. 6 shows diagrammatically the operation of inspection device 30. First, the multiview, polychromatic
30 X-ray probe acquires projection image data (absorption and scatter X-ray data H and L, and transformed data B and I) in a similar way as is done by a 'level 1' X-ray scanner (200).

13

For example, see U.S. Patent Application Serial No. 08|533,646, filed September 25, 1995, entitled "DETECTING EXPLOSIVES OR OTHER CONTRABAND BY EMPLOYING TRANSMITTED AND SCATTERED X-RAY" ~~(ATTORNEY DOCKET NO: 033757011001)~~ which is

5   incorporated by reference as if fully set forth herein). By employing the detection algorithms described in the above-cited application, the polychromatic X-ray probe detects objects within the Z_{eff} window that could contain a threat material (202) and also runs sheet algorithms (204) to

10   identify sheets of a threat material. Then the probe identifies the coordinates of the individual objects and performs a recognition on each object (206). Objects that are identified as free of any threat (or contraband) are cleared and the remaining objects are further examined

15   depending on their shape (208).

        The probe further examines the bulk objects that were rejected (i.e., uncleared) by taking selected radial views (210). The algorithm forms a reconstruction image and locates the objects in the image. Then the algorithm

20   measures the density of these objects (212). The threat decision is automatically made based on a selected density threshold (214). Objects outside of this threshold are cleared (216) and the others (218) need further processing by a second probe, such as the coherent scatter probe (236).

25   This bulk algorithm is faster than a standard CT algorithm since the probe takes only a limited number of the radial views of objects that could not be cleared by the 'level 1' examination (steps 200 to 208). The cleared objects are no longer examined.

30   The probe also examines the identified sheet objects by taking high resolution side views of these objects (220). Usually, the sheet objects are found in the walls of a

examined suitcase or bag. Then the algorithm applies a
selected threat routine (230) to clear objects free of
explosives (or other investigated contraband).
Alternatively, the X-ray probe can here employ only the
5   Compton Scatter technique to examine the walls of a examined
suitcase, as is described in the above-referenced patent
application.

As described above, the second probe employs
coherent (Rayleigh) X-ray scatter to further inspect the
10   objects that could not be cleared (236). The coherent
scatter probe receives coordinates of suspicious objects and
other obscuring objects and identifies the best geometry for
examination. The probe accumulates X-ray data at different
positions and of different energies characteristic of the
15   irradiated material. The probe makes a threat decision by
comparing the acquired data to a database of explosives (or
other contraband) (238). If there is an object that could
not be cleared, another probe such as a Raman probe, an
infrared probe, a microwave probe, or an NQR probe may be
20   employed (240).

Referring to Fig. 4C, Raman probe 300 may be
employed instead of coherent scatter probe 140 to probe
surfaces of the examined items, which could not be cleared
by the coherent scatter probe. Raman probe 300 has a laser
25   source subsystem 305, an optical detector subsystem and a
processor. Laser source subsystem 305 includes a laser, a
scan motor 304 with an associated scan driver 302, and a
focus motor 308 with an associated focus driver 306. Laser
source subsystem 305 can dynamically modify the focus
30   relative to the surface of an irregular item. The
reflected/scattered optical radiation is directed to a Raman
detector 305, which includes a PMT. A programmable set of

optical filters are positioned in front of the PMT by a
filter motor 318 controlled by a driver 316. The optical
filters for the appropriate wavelengths are used for
detection of specific explosives (or other contraband).

5   Alternatively, the reflected/scattered radiation is directed
to several parallel sets of optical detectors, each having a
different substance specific filter; this arrangement can
detect simultaneously multiple substances. Raman probe 300
utilizes different types of optical measurements described

10   in the prior art (see (1) D. N. Batchelder, C. Cheng, I. P.
Hayward, R. J. Lacey, G. D. Pitt and T. G. Sheldon, "Raman
Microscopy and Direct 2-D Imaging of Explosives and Drugs",
pp. 73-75. Office of National Drug Control Policy,
Conference Proceedings Washington, D.C. 1992.

15   K. Carleton, P. Nebolsine, S. Davis, J. Lakovits and R. Van
Duyne, "Detection of Narcotics and Explosives by Surface-
Enhanced Raman Spectroscopy," pp. 401-407. Office of
National Drug Control Policy, Conference Proceedings
Washington, D.C. 1992.

20   Alternative Embodiments
        Alternatively, an infrared probe can be employed
instead of the Raman probe. The infrared probe includes a
IR laser source subsystem, an optical detector subsystem and
a processor. An advantage of the infrared probe is a deeper

25   penetration of the IR laser beam than the visible laser beam
of the Raman probe. A suitable infrared measurement was
described by D.O. Henderson and E. Silberman in "Fourier-
Transform Infrared Spectroscopy Applied To Explosive Vapor
Detection", Proceedings of the First International

30   Symposium on Explosive Detection Technology, pp. 604-617,
November 13-15, 1991.

Alternatively, a dielectrometer probe can be employed. The dielectrometer probe uses a microwave antenna (described in U.S. Patents 4,234,844 and 4,318,108) that excites a standing (constant or pulsed) wave of microwave

5 energy in a fixed field of configuration directed to the suspicious objects. The microwave energy penetrates non-metallic objects and produces a volumetric reflection coefficient. Based on the reflection coefficient, a dielectric constant and loss tangent which are material

10 characteristics. This type of dielectrometric measurements was described by D.C. Steward and T. Yukl in "Explosive Detection Using Dielectrometry, " Proceedings on the First International Symposium on Explosive Detection Technology, S.M. Khan, Ed., Nov. 13-15, 1991; and in the publications cited

15 therein.

Alternatively, a millimeter wave (microwave) probe can be employed, instead of the coherent scatter probe, to create a two dimensional scanned image of the suspicious object. The probe uses a millimeter wave (10 GHz to few

20 hundred GHz depending on the desired penetration) imaging system that gathers amplitude and phase data of reflected waves to reconstruct the wavefronts and create an image. This type of detection is described in detail by D.M. Sheen, D.L. McMakin, H.D. Collins, and T.E. Hall in "Near-field

25 Millimeter Wave Imaging for weapon Detection" SPIE Vol. 1824, p. 223, 1992; and in the references cited therein.

Alternatively, the system employs an X-ray probe using an algorithm which interactively focuses inspection dependent on information gleaned from previous views and the

30 bag topology. The algorithm involves selectively 'looking around' the bag under inspection to measure certain material parameters such as Z_{eff} with much more accuracy. To achieve

higher accuracy, the system selectively sets the beam angle
to avoid clutter detected in previous views, and integrates
the data for longer time periods to minimize statistical
noise. The system 'looks around' by processing the

5   projection image to select slice planes that have the least
amount of clutter, as measured with a 'clutter' algorithm
that is sensitive to rapid material property variations over
a small area. These slice planes are then scanned to find a
closely placed pair of pencil beam coordinates, which see

10   different amounts of threat materials. The pencil beam
coordinates are in close proximity and relatively
uncluttered and thus can be used for a higher precision
measurement of Z_{eff} of the selected object.

     The system inspects certain suspicious areas with

15   much higher resolution and also places material-specific
filters selectively in front of the source or detectors. In
this type of a 'directed search', the results of previous
scans point to the next area and mode of inspection . For
example, in one routine, if a projection scan detects that a

20   part of the lining looks abnormally thick with respect to
the rest of the examined bag (or as compared to a stored set
of bag models), the machine specifically targets this area.
The geometry of the subsequent scan is chosen to maximize
the cross-sectional attenuation; this greatly improves

25   measurement of Z_{eff} and estimated mass and density. Density
is then calculated by measuring the areal density in the
cross-sectional view divided by the length of the thickened
portion wherein the length data are measured obliquely by a
perpendicular scan. By concentrating the X-ray views on the

30   targeted object as opposed to uniformly distributed angular
views around the entire inspection region; the algorithm is

more accurate or faster than a general CT-type scan which performs a standard cross-sectional reconstruction.

Another algorithm interactively searches for specific modalities based on shape, density, or Z_{eff}. The algorithm directs a sequence of material property scans with appropriately selected spatial resolutions and positioning to enable a flexible and targeted material property sensitive inspection. Each additional scan adds information and modifies parameters for subsequent scans for effecting a rapid convergence to a decision on a particular object. This process is performed iteratively. The algorithm can also divide spatial information of a larger bag into several regions and then iteratively process the regions in parallel.

The above-described fully automatic mode, called 'smart x-ray eyes', is an analogue to a human operator with x-ray eyes who can 'look around' the bag to notice 'abnormalities' and see and understand each indicated threat object. Alternatively, the automatic mode is enhanced by providing input from an operator at different stages of the examination. Here, the inspection system includes a graphical interface and a user interface. At different stages, the operator receives one or more images that may also include a color overlay indicating properties of the located objects or regions. Then the operator is prompted to provide optimal selection of inspection geometries for the subsequent scan. This way the algorithm utilizes the experience of a human in an interactive manner.

Another embodiment of the system utilizes a single dual energy x-ray probe and a data interface to the level 1 inspection machine. This enables the system to use the data from the level 1 device to direct the inspection process,

thereby shortening the time to execute the 'level 3' inspection process.

Other embodiments are within the following claims: